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ABSTRACT. The variation of horizonally and vertically polarized centimeter waves reflected from various surfaces on the ground is analyzed. Measurements were taken from an airplane. The sighting angle varied between 0.3° and 75°.

A study of the emittance of natural surfaces in the centimeter range is of great interest for determining the form of the underlying surface or its temperature.** For radiation polarized in a horizontal direction, water will have a small emission coefficient, which makes it possible to readily determine the water-dry land, water-ice, etc. boundaries. Moisture of the soil and roughness of the surface also have a great influence on the polarization characteristics. This makes it possible to use measurements of the polarization characteristics of the underlying surface emission for studying the structure and properties of the surface of the Earth and other planets. /72*

As is known, the electrical properties of the surface being studied have a great influence on the reflection coefficient. Thus, for a quiet water surface the dielectric constant ε equals 80 at the λ = 20 cm wavelength and a

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* Numbers in the margin indicate the pagination in the original foreign text.

** Translator's note: The next portion of this material is illegible in the foreign text.

temperature of $t = 20°$; it sharply decreases as the wavelength decreases. For dry land, the dielectric constant is considerably less than for water. For dry soil, it may amount to two, but for the most part lies between 3 - 20 [1]. The smaller values of ε corresponds to dry, stony, and sandy soils; the larger values corresponds to loam and damp soils. Similarly, the conductivity changes depending on the nature of the surface, as well as the complex dielectric constants.

As was noted above, the nature of reflection from the surface also depends on the dimensions of surface irregularities with respect to wavelength. The Rayleigh criterion may be used for the surface roughness characteristic;

$$h \cos \theta \leqslant \frac{\lambda}{16}, \tag{1}$$

where h is the height of the irregularities, and θ is the zenith angle of incidence of the rays.

It may be seen from this formula that the permissible irregularity heights /73 for specular reflection are determined not only by wavelength, but also depend greatly on the sighting angle θ. The larger they are, the larger is θ. If the irregularities do not satisfy this condition, then reflection becomes semi-scattered, i.e., it approaches diffuse reflection, and the polarization differences in radiation will level out. The shorter the wavelength, the more probable it is that the conditions will be fulfilled under which reflection approaches diffuse reflection. In turn, this pertains to the centimeter wavelength range, where the concept of a "smooth" surface is only applicable for a quiet water surface.

In this article we shall study the dependence of the components (which are polarized vertically and horizontally) of centimeter radiation of natural underlying surfaces upon the sighting angle. Similar data are also given in [2, 3].

Technical data on the apparatus and measurement method. The polarization measurements of radio emission of various types of underlying surfaces were performed in Autumn, 1968, using a three-cenitimeter radiometer operated by S.T. Yegorov and placed on the IL-18 airplane [4]. The radiometric equipment consisted of a parabolic antenna having a diameter of one meter and a superheterodyne receiver, whose sensitivity was 1.5°K for a constant time $\tau = 1$ sec. With angular shifting of the mirror, the antenna made it possible to scan by line within the limits $\pm$ 30° from the normal, perpindicular to the direction of flight. A ferrite polarizer was placed at the radiometer input, which made it possible to receive alternately both components of the signal linear polarization.

The main parameters of the radiometric apparatus were as follows.

1. The width of the directional diagram on both polarizations: along the half power level it did not exceed 2°; along the zero level is was 5°.

2. The antenna directional diagram width was changed during scanning between $\pm$30°: along the half power level 1.10°; along the zero level 1.5°.

3. The decoupling between the polarization channels was no less than 20 decibles.

4. The antenna scattering coefficient $\beta = 0.22$. During the antenna scanning β increased to 0.27. The apparatus was calibrated based on the radio emission of a water surface before the flight.

The aircraft studies of radio emission of an underlying surface on both polarizations were performed for sighting angles of θ equalling 0.30, 45, 50 and 75°. The angle $\theta = 0°$ corresponded to an antenna directed at the nadir; the angle $\theta = 30°$ -- to an antenna located at the outmost position. The sighting angle was increased further by banking the aircraft while the antenna was secured in the outmost position, opposite to the banking direction.

Thus, when turning the aircraft banking was 15, 30 and 45°, while the radius of the circle described by the aircraft ranged from 5000 to 2000 m. Banking up to 30° was maintained by the automatic pilot, while banking at 45° was done by hand within an accuracy of 1 - 2°. The flights were carried out at an altitude of 1500 - 2000 m. For the measurements, extended sections of a uniform surface were selected. The degree of uniformity of the selected surface was determined visually, and also based on oscillations in the radio brightness temperature.

Processing of measurements results. The radiometric apparatus gave measurement results which made it possible to obtain the antenna temperature from which it was necessary to change to the radio brightness temperature. /74
In the general case, the expression for the antenna temperature has the following form:

$$T_a = \frac{\int_{4\pi} T_b(\Omega) F(\Omega)\, d\Omega}{\int_{4\pi} F(\Omega)\, d\Omega}, \tag{2}$$

where $T_b(\Omega)$ - distribution of radio brightness temperature at a solid angle; $F(\Omega)$ - antenna directional diagram.

Separating the region of the main and side lobes, we may write expression (2) in the following form:

$$T_a = \frac{\int_{\Omega_m} T_b(\Omega) F(\Omega)\, d(\Omega)}{\int_{4\pi} F(\Omega)\, d\Omega} + \frac{\sum_{i=1}^{n} \int_{\Omega_i} F(\Omega_i)\, T_b(\Omega_i)\, d\Omega_i}{\int_{4\pi} F(\Omega)\, d\Omega}, \tag{3}$$

or

$$T_a = T_{b_m}(1-\beta) + \sum_{i=1}^{n} T_{b_i}\beta_i, \tag{4}$$

where β is the total antenna scattering coefficient, T_{b_i} - radio brightness temperature of the emission of different zones outside of the main lobe, β_i scattering coefficient for different zones with T_{b_i}.

From (4) we may determine T_{b_m}.

$$T_{b_m} = \frac{T_b - \sum_{i=1}^{n} T_{b_i}\beta_i}{1-\beta} \tag{5}$$

Thus, for determining T_{b_m}, we must know the value

$$\sum_{i=1}^{n} T_{b_i}\beta_i = T_{b_{ba}}. \tag{6}$$

It is not possible to calculate it, since the components $T_{b_i}\beta i$ are unknown. Therefore, it was determined experimentally using the substitution method. For this purpose, before the apparatus was placed on the airplane, the antenna and a model of a section of the aircraft were placed on a special stand, making it possible to change the angle of elevation from 0 to 90°. A disk was placed a certain distance from the antenna, made of an absorbing material with a known radio brightness temperature T_{b_d}. On the background of the sky, two measurements were made of the antenna temperature; with the disk and without it [4]. The disk had dimensions corresponding to a solid angle of the main lobe of the antenna directional diagram. The antenna scattering coefficient was determined from these measurements. After this, the antenna was aimed at the underlying surface, (water, ice, plowed field) at an arbitrary angle, and its antenna temperature T_{a_e} was measured, which equaled

$$T_{a_e} = T_{b_d}(1-\beta) + \sum_{i=1}^{n} T_{b_i}\beta_i, \tag{7}$$

From this, the radio brightness temperature of the background was readily /75
determined:

$$T_{b_{\phi}} = \sum_{i=1}^{n} T_{b_i}\beta_i = T_{a_e} - T_{b_d}(1-\beta). \tag{8}$$

The values $\bar{T}_{b_{ba}}$ for different underlying surfaces are shown in Table 1 as a function of the sighting angle.

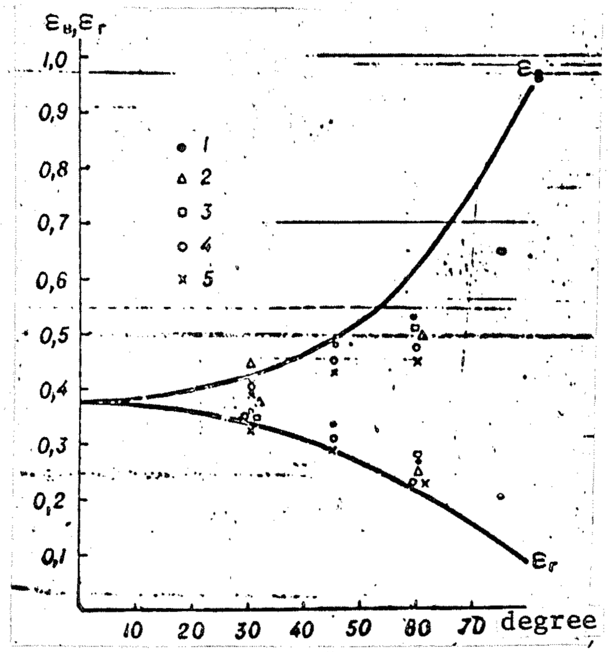

Figure 1. Dependence of emission coefficient of a water surface on sighting angle:

1. Ladozhskoye Lake, 21 December 1968, Swells 0 - 1 points;
2, 3, 4 - Kaspiyskoye Sea, Swells 1-2, 2-3, 4-5 points, respectively;
5 - Black Sea, Swells 1 - 2 points.

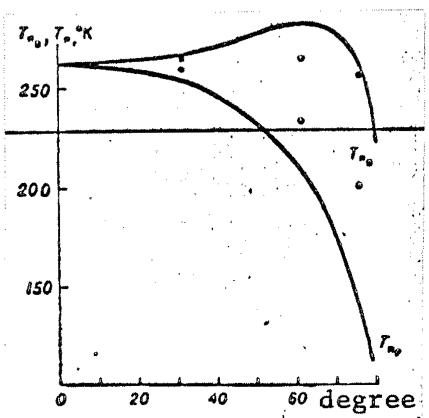

Figure 2. Dependence of radio brightness temperature of a sandy desert on sighting angle.

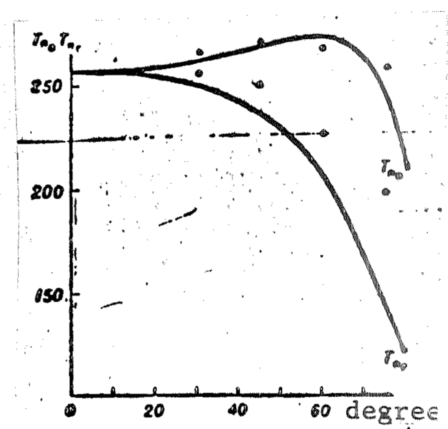

Figure 3. Dependence of radio brightness temperature of a rocky desert on sighting angle.

TABLE 1

Type of underlying surface	Type of polarization	$\bar{T}_{b_{ba}}$ °K		
		θ = 0°	θ = 30°	θ = 60°
Water (0%, T_n = 283°K)	vertical	20	24	28
	horizontal	20	25	30
Sand (T_n = 283°K)	vertical	55	58	60
	horizontal	55	60	64
Plowed field (T_n = 283°K)	vertical	50	53	56
	horizontal	50	58	60

For aircraft measurements, with sufficient accuracy we may assume the average values of $\bar{T}_{b_{ba}}$ obtained as a result of an experiment on the Earth.

Since the antenna had a rather narrow directional diagram, the value of $\bar{T}_{b_m}$ corresponds to the average value of the radio brightness temperature within the limits of a solid angle of the main lobe. To obtain the real values of the radio brightness temperature of an underlying surface, it is necessary to determine the contribution of radio emission from the atmosphere. Estimates showed that the influence of the atmosphere is insignificant, and is 3 - 5°K when the sighting angle changes from 0 to 75°. /76

Analysis of measurement results. The measurements were performed for the following underlying surfaces: water (fresh, salt) having varying degree of swells, sandy desert, rocky desert, plain covered with snow, sand with loam, etc.

The radio emission of a water surface was measured in the Kaspiyskiy and Black Sea regions, as well as the Ladozhskoye Lake with swells from 0 - 1 to

4 - 5 points. The temperature of the water surface in the Kaspiyskoye and Black Seas changed between 10 - 12°, and in the Ladozhskoye Lake it was 6°.

The experimental values obtained for the radio brightness temperature were used to calculate the emission coefficients ε of a water surface for two linearly polarized components pertaining to the emittance of water at a temperature of 283°K and a salinity of 20%.

Figure 1 gives the values of ε as a function of the sighting angle. The graph also presents the theoretical values of ε calculated for a quiet water surface with T_s = 283°K and a salinity of 20% (solid curves). The data point to a divergence between the experimental and calculated data, which coincides satisfactorily only for small sighting angles. This may be explained by the fact that the calculations pertain to an ideally smooth water surface. The real water surface has swells, in which case -- as already indicated -- the difference between the emittances for vertically and horizontally polarized emission coefficients decreases. A comparision of the results obtained with the experimental data given in [2] shows their good agreement.

Studies of radio emission of a sandy surface were performed in the sandy regions of central Asia. Primarily the underlying surface was a sandy or a rocky desert with sand dunes and sparce vegetation. By way of an example, /77 Figure 2 gives the radio brightness temperatures of a sandy surface for two polarizations obtained during a flight close to Ashkhabad, 30 November 1968. The calculated curves of the radio brightness temperature are plotted here for an ideally smooth sandy surface, having the following absorption and refraction indices: n = 1.79, χ = 0.0174 and a temperature of 285°K.

Similar measurements were also performed for sections of the rocky desert in the region of Nebit-Dag. The research data are given in Figure 3, where the theoretical values of the radio brightness temperatures are also plotted, calculated for n = 1.674 and χ - 0.01 at a temperature of 283°K.

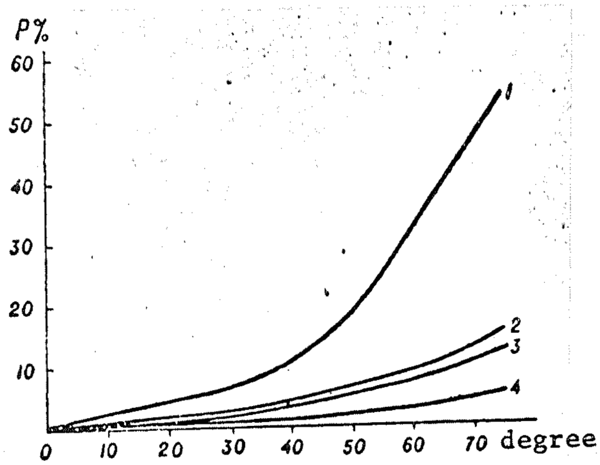

Figure 4. Dependence of polarization coefficient on sighting angle.

1. water surface; 2. sandy desert; 3. rocky desert; 4. plain, covered with snow.

Analyzing the measurement results presented in Figures 2 and 3 we may note that there is a small difference between the vertically and horizontally polarized components of radio emission of these surfaces for sandy and rocky deserts. We may also note that there ais a slight change in ε_{vert} with an increase in the sighting angle. This occurs because the real surface structure of sandy and rocky deserts differs significantly from an ideally smooth surface. The effect of structure on the polarization of radio emission of various surfaces is clearly apparent in Figure 4, which gives the experimental relationships between the polarization coefficient

$$P = \frac{T_{f_{ba}} - T_{f_s}}{T_{f_{ba}} + T_{f_s}} \tag{9}$$

and the sighting angle θ,

The largest polarization coefficient values are obtained for water, whose surface properties approximate a mirror surface.

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